Real Time Analysis of ECG Signal for Baseline Wander Removal and R Peak Detection Using Discrete Wavelet Transform

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Prof. Susmita Das

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Department of Electrical Engineering

National Institute of Technology, Rourkela

Dedicated

to

The Dreams and Sacrifices

of my Dear Ones

who Love me a Lot.

Department of Electrical Engineering
National Institute of Technology, Rourkela

Prof. Susmita Das
Associate Professor

26 May,2016

Supervisor's Certificate

This is to certify that the work presented in this dissertation entitled "Real Time Analysis of ECG Signal for Baseline Wander Removal and R Peak Detection Using Discrete Wavelet Transform" by Sambit Kumar, Roll Number 711EE1054,submitted to the National Institute of Technology, Rourkela for the award of, is a record of bonafide research work carried out by him in the Department of Electrical Engineering, under my supervision and guidance in partial fulfilment of the requirements of the degree of ***Master of Technology(Dual Degree) in Electrical Engineering***.

....
Supervisor's Signature
Prof. Susmita Das

Department of Electrical Engineering
National Institute of Technology, Rourkela

Declaration

I, *Sambit Kumar*, Roll Number *711EE1054* hereby declare that this dissertation entitled ”Real Time Analysis of ECG Signal for Baseline Wander Removal and R Peak Detection Using Discrete Wavelet Transform” represents my research work carried out as a postgraduate student of NIT Rourkela. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the section ”Bibliography”. Hereby, I declare that this dissertation is a reproduction of previously existing research work. I have also submitted my reproduced research records to the scrutiny committee for evaluation of my dissertation. I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

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26 May, 2016 *Sambit Kumar*

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Abstract

Inspiration of this project is from the need to find an efficient method for analysis of ECG signal which needs to be simple, have good accuracy and have less computational time. As the main cause of death around the globe is being led by heart related diseases, hence a recent study shows that in the working age group of around 24-65 years, the death percentage of 25 is only because of the various heart related diseases. Hence ECG is the most important signal for consideration and observation to prevent these issues. ECG is a bio medical signal which can be detected by using electrodes placed in the particular locations of human body.

In my research work there are two stages for the efficient analysis of ECG signal. Primary stage is the enhancement of ECG signal, that is removal of noise. It is done by extracting the required cardiac components by rejecting the background noises mainly Baseline Wander noise which is a low frequency noise and generally lies below 0.5 Hz. This is done by using a traditional MA filter method and by using wavelet theory. This thesis work focuses on the algorithms proposed for enhancing for both methods and finding out the correlation for the enhancement.

Secondary stage is to determine the R peak using DWT and perform the signal reconstruction. This work also follows a proposed algorithm along with the comparison for getting a better detection which can be used for the required operations in the typical ECG signal.

The simulation is done in the MATLAB environment. The results are shown in the view to compare the different methods to denoise signal with baseline wander and also the comparison of different threshold methods for appropriate detection of R peaks for fast and accurate computation.

***Keywords*: *Electrocardiogram (ECG)*; *Discrete Wavelet Transform (DWT)*; *Baseline Wander*; *Moving Average (MA) Filter*;**

List of Acronyms

Acronym	Description
ECG	Electrocardiogram
Na	Sodium
K	Potassium
SA Node	Sinoatrial Node
AV Node	Atrioventricular Node
MA Filter	Moving Average Filter
BW	Baseline Wander
DWT	Discrete Wavelet Transform
SNR	Signal to Noise Ratio
TP	True Peak
FP	False Positive
FN	False Negative

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CHAPTER 1
INTRODUCTION

1 Introduction

Electrocardiogram (ECG) is a biomedical signal important for observing heart related diseases. ECG helps us to import information related to heart[1]. ECG signals are non-stationary signals whose visual analysis is difficult to obtain. Therefore through computerized computations we can go for easy ECG signal analysis.[2][3]

There are two types of monitoring methods for ECG, they are manual and computer based detection method. In former method an ECG signal is taken from the patient body and is printed on a graph paper and then checked visually for the decisions to be taken. This method is not apt for long run as the signal collected accumulates a lot of noise with it, hence the point for proper detection is not lucid. While in the latter method ECG signal is processed through a computer system therefore it is abt for long run monitoring.

Often during transmission of ECG signals there are results noise in the system so it leds to signal corruption.[5] Noises responsible for ECG signal corruption include powerline interference which lie around 50-60 Hz, Baseline wander (less than 5Hz),improper electrode site preparation etc. Hence we always get error results while analyzing ECG signals. Therefore first and foremost thing done before analysis is denoising the signal also referred as signal enhancement.

1.1 Human Cardiac System

In Human Cardiac system there are several parts out of which heart is the central organ. Through this system, the total blood circulation is processed entirel. The following representation of the above is shown in 1.

A heart has two sections namely right and left. These sections are again divided into chambers known as atrium and ventricle. The former which is the upper chamber is the blood receiving one while the latter is the transmitting one. These atria are attached by non-conducting fibrous tissue to the ventricles for keeping them isolated electrically [5]. For isolating the left and right atriums there is a valve known as tricuspid valve where the left side of atria and ventricles are separated by mitral valve. [6].

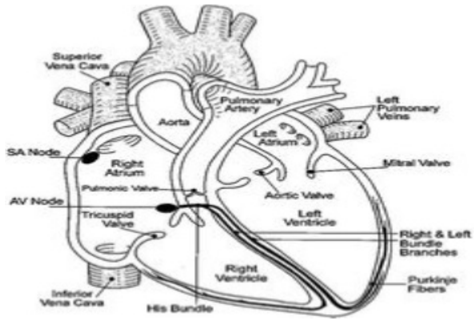

Figure 1: Human Cardiac System [1].

1.2 ECG Generation

The right part of heart receives the blood without oxygen form whole body with the help of superior and inferior vena cava. Then it passes through tricuspid valve, pulmonary atria and then finally to lungs. Here the blood is filled with oxygen which is then passed through the left part with the help of the mitral valve. After passing through these the blood is purified which is then circulated in the entire body with the help of aorta. While circulating, the depolarization process follows where positive ions Na+ passes the heart cell thereby introducing a potential between heart's inside and outside cells. In the same manner in repolarization process, potential is developed which is larger than the pacemaker's threshold value of electric pulse, which is produced by SA node. These pulses then travel from right to left for contracting and generating the P wave. After this, they arrive at the AV node which is responsible for contracting ventricles. Thus help in producing QRS component. After this the signal travels through His bundle, and finally through Purkinje fiber thereby causing ventricles depolarization for generating T wave. This entire process is represented in the figure below

1.3 ECG signal details

The following signal contains five details which gives us details of the components of an ECG signal.

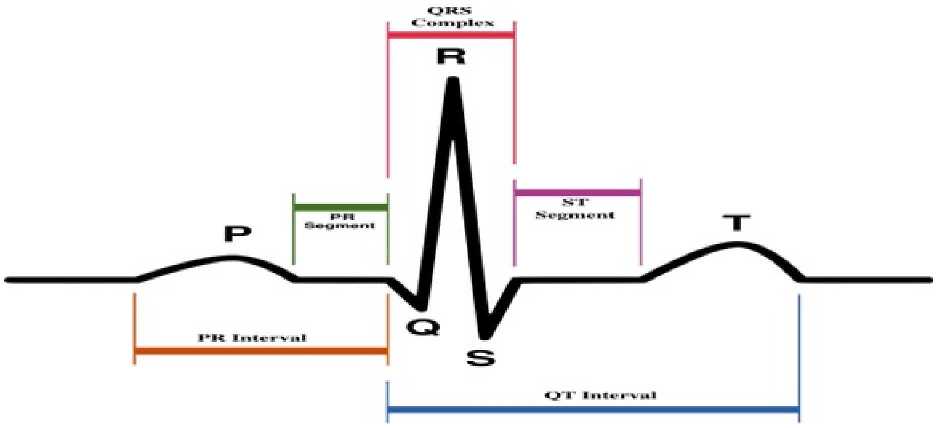

Figure 2: ECG Signal Components [5].

Signal	Frequency Range(Hz)	Amplitude Range(mm)	Duration(sec)
ECG	0.01 - 300	0.05 - 3	
P-Wave	0 – 5	< 2.5	< 0.12
QRS Wave	0 – 20	< 10	0.06 – 0.12
T-Wave	0.5	< 5	0.1 – 0.25

Table 1: Description of ECG components

1.4 Motivation

ECG is a pointer to all health conditions of human being as well as it mirrors cardiac heart state. ECG provides various detailed knowledge of heart diseases if it is properly analysed. Because of its non-stationarity, irregularities may show non periodic nature hence diagnosis may be altered. Detection of ECG clinically takes long time and is very tedious. Also as visual analysis is non reliable hence the need for computer based method pertains.[8].Therefore by analyzing the fetal ECG we can detect the actual con-dition[9][10]. For beat detection and the classification on ECG signals various contributions have been done in both domains. But the major problem faced while coding is the morphological variation of ECG signals. Hence we need to come up with simple computation methods having com-promising efficiency to analyze ECG signals. We have implemented Discrete wavelet Transform (DWT) for its efficiency and some thresholding techniques for the R peak detection efficiency and simplicity. Overall we have tried to minimize the computational time and maximize the efficiency.

1.5 Objective of Thesis

On the basis of motivation it is clear that importance of ECG analysis is very high in Biomedical Signal Processing .The following things are focused in this research work:

- To design a MA filter to remove the BW noise from an ECG signal and then compute the correlation with the denoised ECG signal.
- To implement DWT on an ECG signal by adding BW noise.
- To compare the different thresholding techniques on the ECG signals with different SNR values and form a tabulation.
- To determine the R peak after reconstruction by applying two threshold techniques and then find the different components for different datas from MIT-BIH Database.

1.6 Organization of Thesis

This thesis including current chapter contains five chapters.Following is the orientation of my remaining thesis:

1.6.1 Chapter 2:

Gives the literature survey of the work described. For this survey a number of literature reviews on ECG signal processing have been undertaken. As my research work have immense importance on signal enhancement and R peak detection hence it is divided into two sections.

1.6.2 Chapter 3:

Here the Proposed Algorithms are implemented for evaluating the required parameters on the basis of my research work.

1.6.3 Chapter 4:

After implementation the Results obtained experimentally are discussed and the performance parameters are computed.

1.6.4 Chapter 5:

As the last chapter, here conclusions, future scope and the limitations are discussed observed during the research work.

Chapter 2
Literature Survey

2 Literature Survey

A vast amount of research has been done by various researchers in this current perspective. Out of these some research work motivated me to implement algorithms for the analysis of ECG signals. This research work include removal of Baseline wander noise by applying moving average filter and DWT and also detection of R peak while reconstruction during denoising. This survey is described in the following:

2.1 Baseline Wander Noise Removal

Dai $et al.$ (2009)have proposed a filter for signal enhancement. In this type of filter, the low frequency BW noise is selected and captured and finally removed to extract the original true ECG signal. Here the noise is extracted by a low pass filter.This is a simple and easy to implement method used for noise removal for its high prcessing speed but there are possibilities of data loss from the filtered ECG signals.

Lin et al. (2013) have proposed two main research works. Out of which, one being the removal of noise using Discrete Wavelet Transform. Here we use Symlet wavelet(sym5) for the wavelet functioning and for the thresholding purpose soft thresholding is used. Hence by applying the required algorithm we can reduce the BW noise from the ECG signal. It is an advanced method where we can remove number of noises with reduced complexity and losses.

2.2 R wave Detection

Lin $et al.$ (2013) have also proposed a method for this. Here for capturing the peaks, algorithms such as one threshold and two thresholds are applied and then compared for better results. Hence R Peak is detected which is used for heart rate calculation.

2.3 Summary

Hence in this chapter, we surveyed the method to design a MA filter for signal enhancement. We also surveyed for the algorithms necessary for DWT implementation on the typical ECG data. We found various thresholding techniques to reconstruct the decomposed signal and to find the R peak component for evaluating the sensitivity.

CHAPTER 3
PRPOSED ALGORITHM

3 Proposed Algorithms

3.1 Overview

This research work has been divided into two tasks. First task is to remove BW from the signal using two methods, they are moving average filter and discrete wavelet transform. Second task is to detect the R peak for the R wave detection using one threshold and two thresholds method.

3.2 Proposed algorithm for Baseline Wander Removal using Moving Average filter

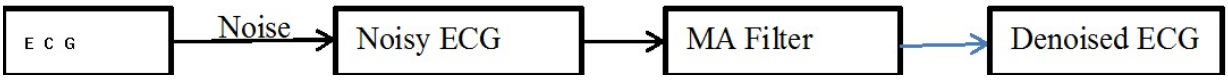

Figure 3: Block Diagram for Moving Average Filter.

In this proposed algorithm, an ECG signal having a frequency of 360 Hz and 3600 samples. Then the raw data is converted to physical data after subtracting with base and then dividing with gain. An additional BW noise is created which is the a sinusoidal wave for the testing of algorithm. Then this artificial noise is linked with signal to get a noisy signal. Now the noisy signal is passed through the Moving Average filter which basically is a low pass filter. As the BW noise is a noise with less frequency, hence we can remove the noise using this filter and finally obtain a denoised ECG signal.

3.2.1 Moving Average Filter

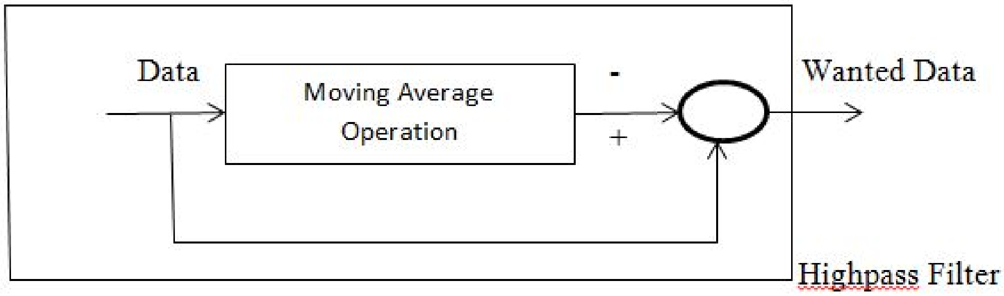

Figure 4: MA Operation.

A moving average filter is proposed for easy implementation and calculation, of the data required for observation by filtering out the noise.

Its difference equation is

$$y(n) = \frac{1}{N}\sum_{n=0)}^{N-1}(x(n-i))$$

Here for testing we need to generate an artificial sinusoidal signal of 0.2 Hz and add it with the main signal to get the desired output shown below:

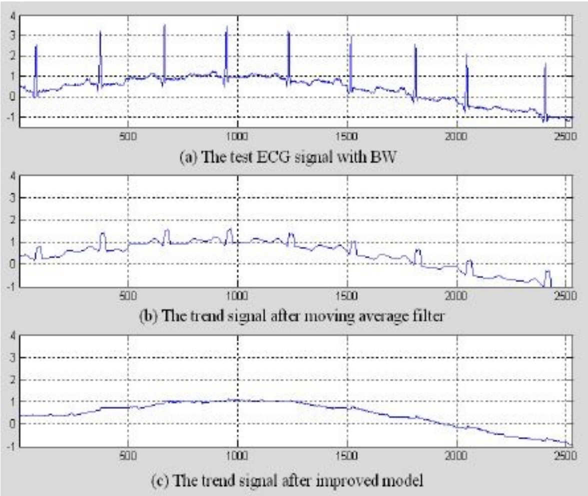

Figure 5: The signal with BW.

3.3 Proposed algorithm for Baseline Wander Removal using Moving Average filter

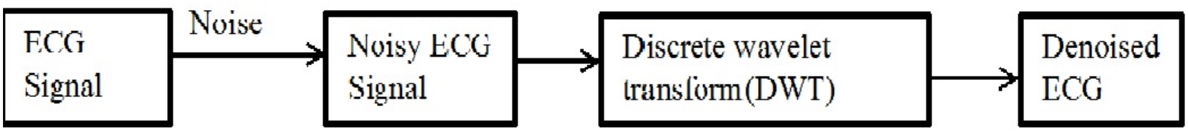

Figure 6: Block Diagram For Discrete Wavelet Transform.

In this proposed algorithm, a BW is added to signal to make it noisy. This noisy ECG signal undergoes Discrete Wavelet Transform which divides the wavelets into different level coefficients following the sub band code algorithm. Then these coefficients are reconstructed to obtained a denoised ECG signal.

3.3.1 Discrete Wavelet Transform

DWT uses two filters for signal analysis and to reduce computational time. The Filter banks have two types of filters, namely High pass filter and low pass filter whose cut-off frequency is half bandwidth of the main signal. This analysis involves combination if down filtering and downsampling by the factor 2. For reconstruction purpose the upsampling by the factor 2 and then zeros are inserted for combinations process in reconstruction.

For the denoising of wavelet during Discrete Wavelet Transform, we need thresholding methods to either remove coefficients below the threshold value detrmined by the noise variance or to shrink the wavelet coefficieents above and below the threshold, They are Hard and Soft thresholding techniques.

In the proposed algorithm, soft thresholding is used for low frequency noise shrinking.

3.3.2 Hard Threshold

It is also known as kill or keep method. It performs better in maintaining the precision of the signal. The absolute value of the coefficients is taken.

$$c\widehat{D}_j = \begin{cases} cD_j, & |cD_j| \geq t \\ 0, & |cD_j| \leq t \end{cases}$$

3.3.3 Soft Threshold

It helps in reducing coefficients towards zero giving a smooth signal. It follows nonlinear transform for its operation.

$$c\widehat{D}_j = \begin{cases} sign(cD_j)(|cD_j| - t), & |cD_j| \geq t \\ 0, & |cD_j| \leq t \end{cases}$$

Here we subtract the reconstructed cA8 component from the raw signal to get a denoised image. Due to the fact the baseline wander frequency lies below 1Hz and as the cA8 component has a frequency level from 0 0.7. Hence we can do the operation.

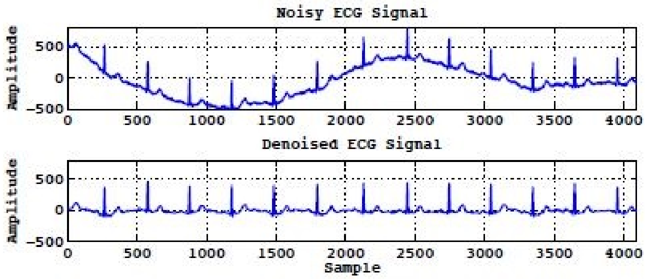

Figure 7: Enhanced signal.

3.4 Proposed Algorithm for R peak detection

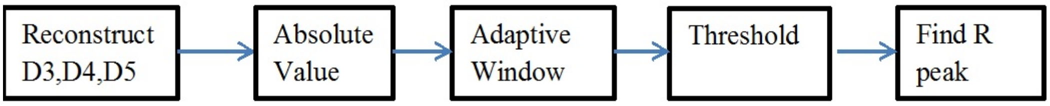

Figure 8: Block diagram of proposed algorithm

This proposed algorithm is DWT algorithm. After decomposing the ECG signal into various levels(eight levels according to my research work) , the R peak detection process starts. The foremost thing here is the reconstruction of third, fourth and fifth level decomposed wavelets. The reason here for neglecting the first and second decomposed wavelet is due to the fact that they contain high frequency components. The sixth, seventh and eighth components have very low frequencies and hence can be discarded. After reconstruction process, the absolute value of the reconstructed signal is taken in order to get the localized coefficients. This process is followed by application of adaptive window where windows of 0.5 s is taken with the window moving every 0.1 s. In this window, the threshold method is applied. Here two types of threshold methods are applied to get a clear result of the signal where we can find R peaks required for the R wave detection. After finding R peaks we can go for the heart rate calculation as

$$HealthRate = \frac{60}{R - R_{interval}} bpm \tag{1}$$

The threshold method used here is

$$thr(i) = \alpha max(y_m(i - s : i)) \tag{2}$$

Here α is the value obtained after getting the first maximum position value and then applying that value for thresholding givin us a second maximum value after 5s.

s is 5 seconds(1800 samples)

To get a better result we also use the second threshold method along with the first threshold

$$RR[n] = \frac{1}{8}\sum_{a=1}^{8} RR[n-a] \tag{3}$$

RR is the RR interval obtained.

3.5 Summary

In this chapter we came to know about the algorithms proposed to be implemented in the thesis work for obtaining the enhanced signal. We also came to know about the thresholding techniques used for detecting the R peaks so that we could find the required essential parameters.

CHAPTER 4
RESULTS AND DISCUSSIONS

4 Results and Discussion

4.1 Overview

This chapter deals with the thesis results which are obtained after applying the proposed algorithms described in Chapter 3. For obtaining the final results, an ECG of record number 100 is taken from MIT-BIH Database for the required operations. For finding the R peak a 30minutes duration ECG signal is taken to detect the required parameters. For this various ECG signals are taken from same database. They are record numbers from 100-109, 111-119,121-124. They are evaluated for obtaining the efficiency of the algorithms.

4.2 Software for Simulation

The software used here for the simulation is MATLAB R2015a. As the proposed algorithms have been arranged in the previous chapter, same way the results are discussed below accordingly.

4.3 Results and Discussions for Removal of Baseline Wander using Moving Average Filter:

For evaluating the performance of Moving Average filter on the ECG signal noised with artificial baseline wander obtained by the sinusoidal wave of 0.2Hz.

Step by step analysis of proposed algorithm:

1. An ECG signal

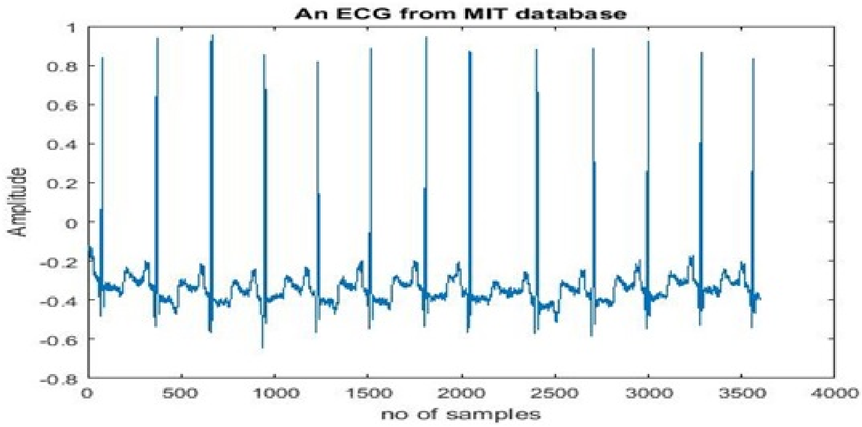

Figure 9: ECG signal

2. Now adding noise to original ECG signal

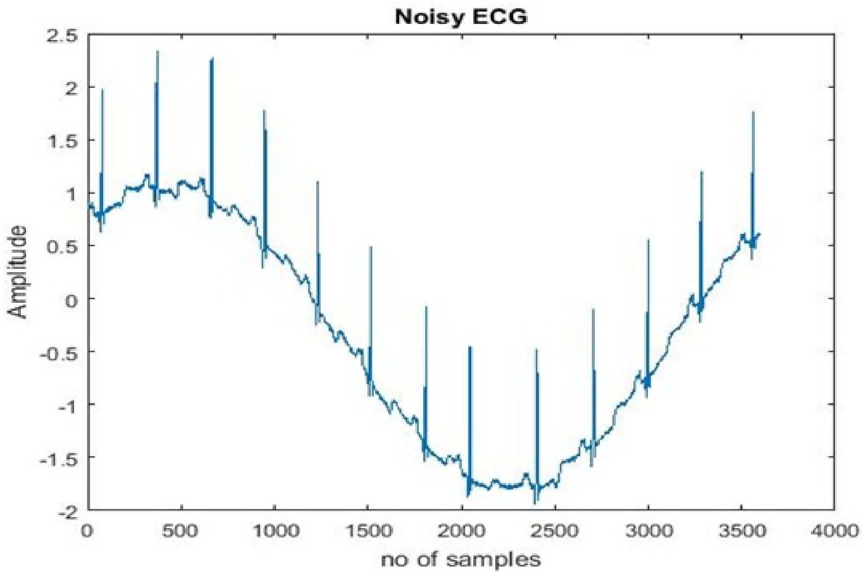

Figure 10: ECG signal after adding noisy signal.

3. Now removing low frequency noise by applying moving average filter

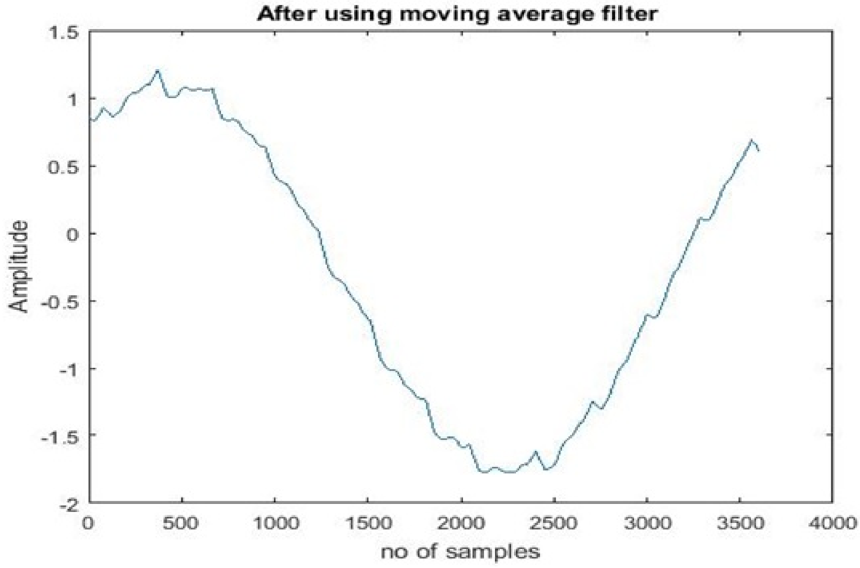

Figure 11: ECG signal after removing low frequency noise

4. After subtracting the low frequency from the original signal we get the final enhanced ECG signal.

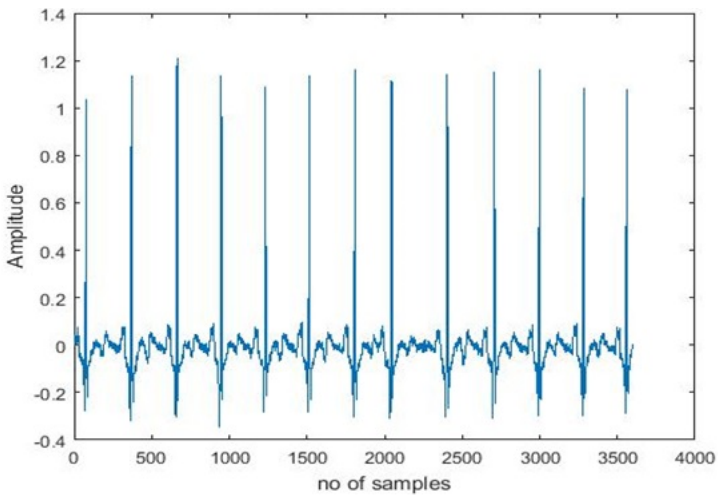

Figure 12: ECG signal without baseline water

To quantify the performance of this moving average filter during ECG enhancement, we calculate the correlation coefficient given by

$$\rho_{xy} = \frac{\sum_{n=0}^{N} x(n)y(n)}{(\sum_{n=0}^{N} x(n)^2 \sum_{n=0}^{N} y(n)^2)^{0.5}} \tag{4}$$

After computing for ECG signal of MIT/BIH 100m database, the correlation coefficient is found out to be 0.9273.

4.4 Results and Discussions for Removal of Baseline Wander using Discrete Wavelet Transform:

For evaluating the DWT on the signal noised with artificial BW noise.

Now we follow the step by step process of the following algorithm:

1. An ECG signal

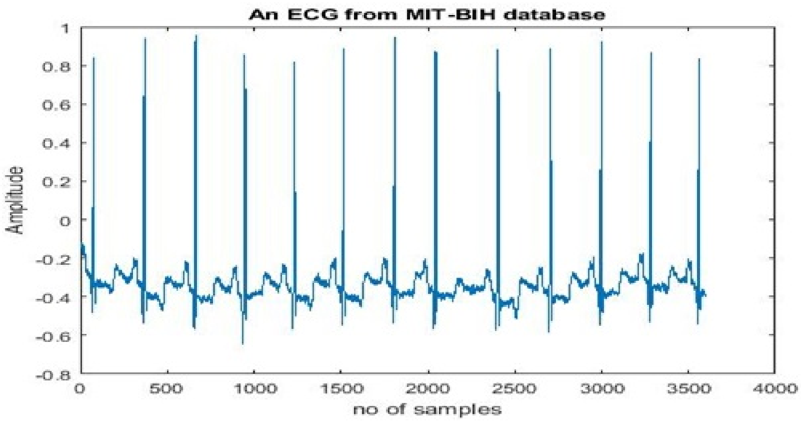

Figure 13: ECG signal

2. BW noise

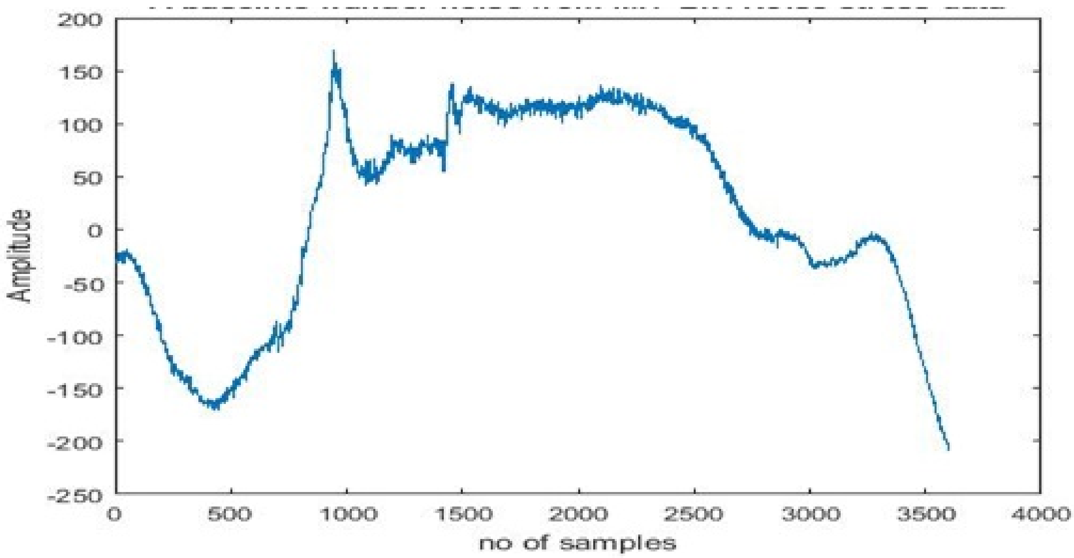

Figure 14: Trend BW

3. Adding both the signal for evaluating the proposed algorithm, we get a noisy ECG signal.

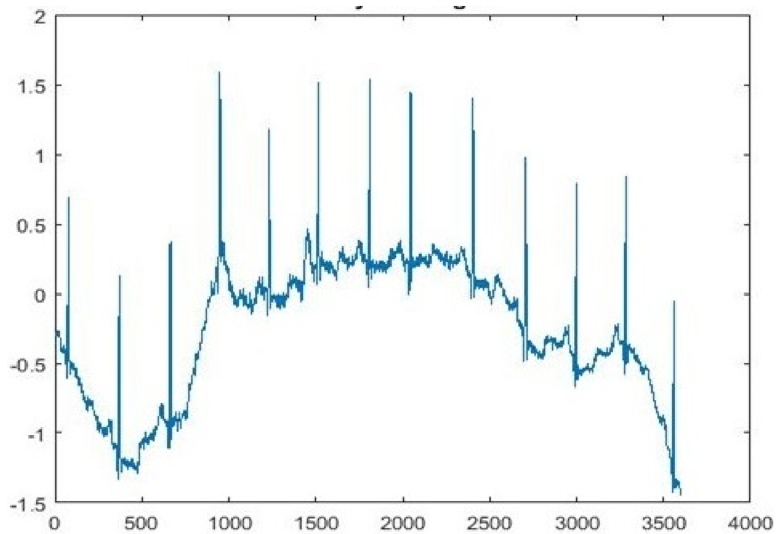

Figure 15: ECG signal after adding both the signals.

4. For performing we need to apply thresholding, soft thresholding is used for the wavelet coefficients to shrink the low frequency signal to near zero below the threshold and to obtain a smooth signal

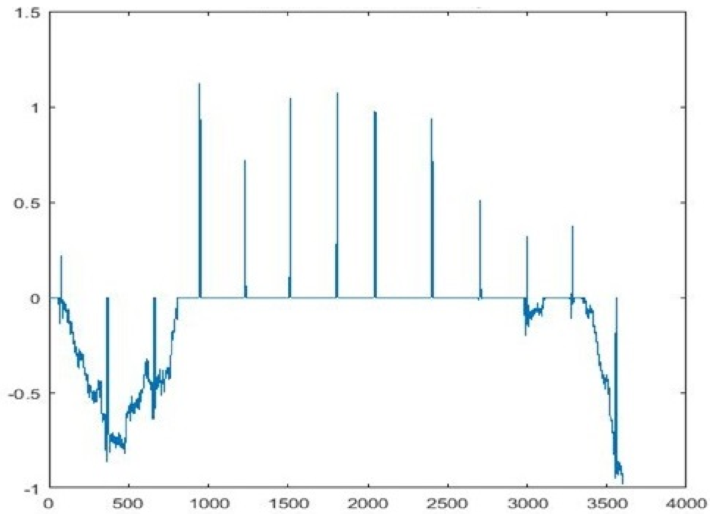

Figure 16: ECG signal after soft thresholding.

5. Reconstructing the signal after decomposition for getting the enhanced ECG signal .

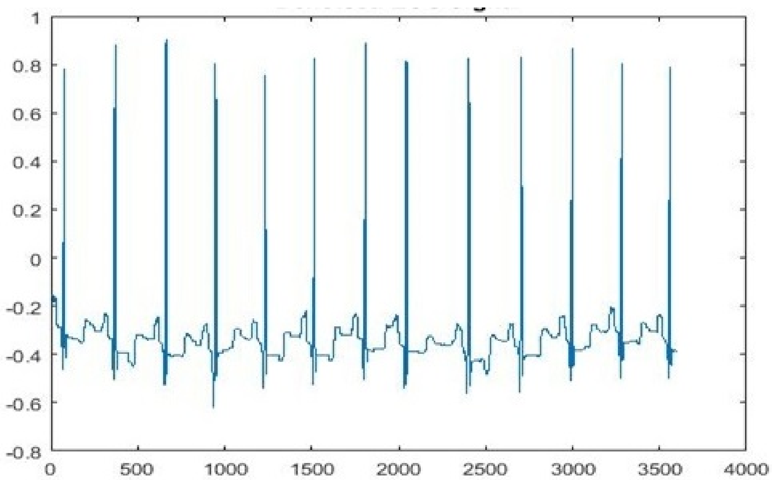

Figure 17: Diagonised ECG signal.

After computing for ECG signal of MIT/BIH 100m database, the correlation coefficient is found out to be 0.9231. After denoising we find the SNR of the input signal and for the output enhanced ECG signal by following the proper formula:

$$SNR_i = 10\log_{10}\left[\frac{\sum_n x^2(n)}{\sum_n r^2(n)}\right] \tag{5}$$

$$SNR_{\alpha} = 10\log_{10}\left[\frac{\sum_n x_d^2(n)}{\sum_n (x_d(n) - x(n))^2}\right] \tag{6}$$

While performing DWT, we need to used some thresholding methods for the decomposition process. There are two types of thresholding used in general. After using both the thresholding on the composed noise signal we get the following plot:

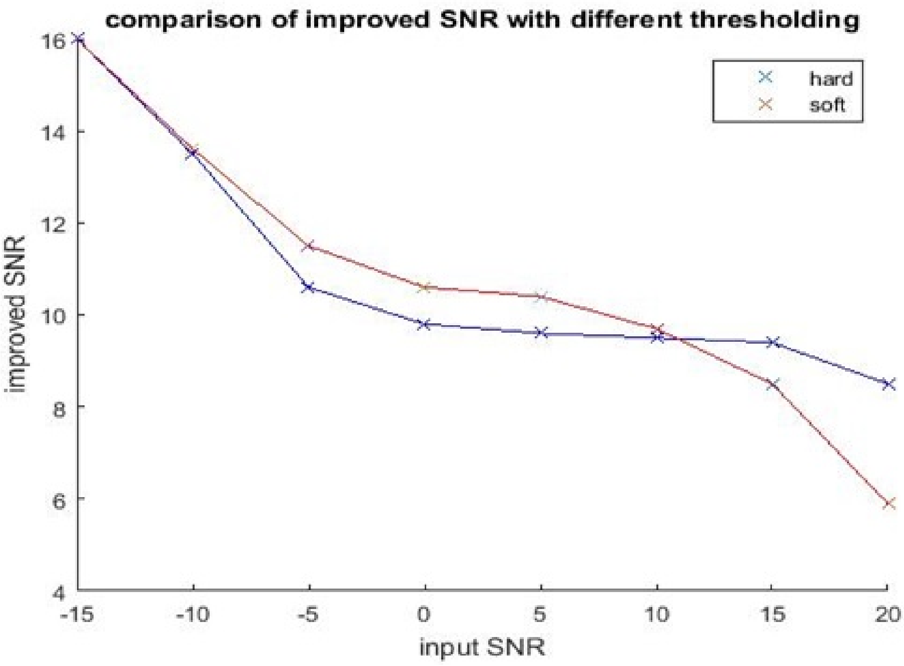

Figure 18: Comparison of improved SNR with different thresholds.

	Hard	Soft
Input SNR (db)	Improved SNR (db)	Improved SNR (db)
-15	16	16
-10	13.5	13.6
-5	10.6	11.5
0	9.8	10.6
5	9.6	10.4
10	9.5	9.7
15	9.4	8.5
20	8.5	5.9

Table 2: Comparison of improved SNR with the thresholding methods.

4.5 Results and Discussions for R peak using Discrete Wavelet Transform:

In this research work or detecting R peak we follow two types of threshold methods. One is one threshold method in which we obtain the R peaks with lesser details, hence the results are fixed better by going for a two threshold method.

- First we need to follow the reconstruction process for the following decomposed signals.

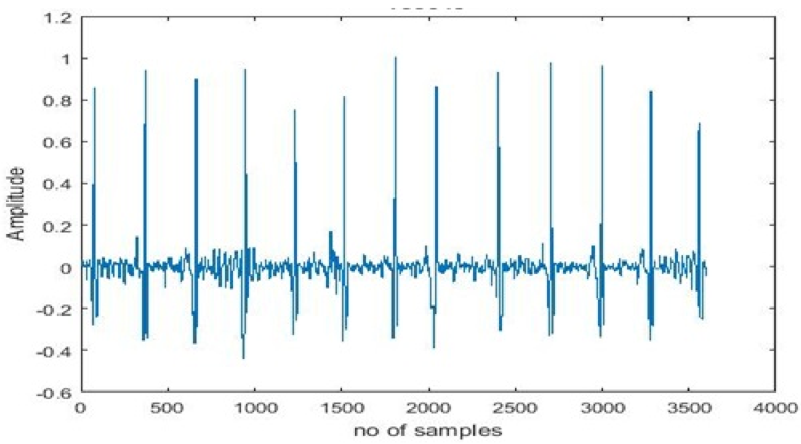

Figure 19: Reconstruction of decomposed signals.

- Now we need to take the absolute value for getting a localized signal.

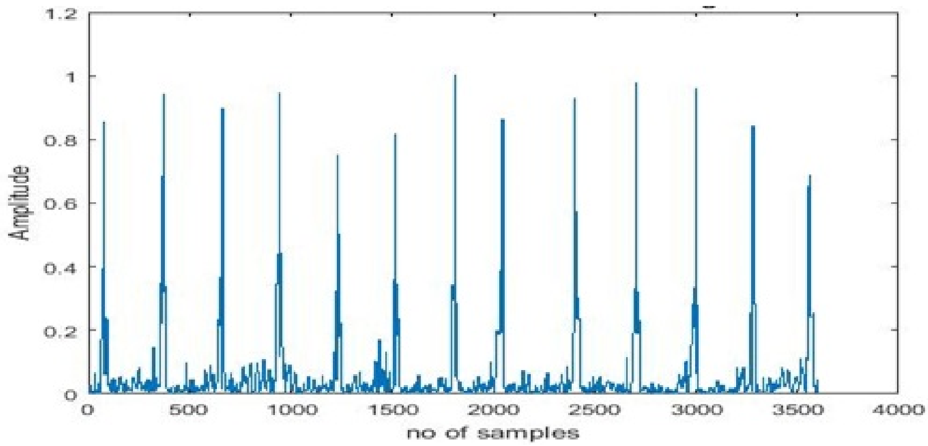

Figure 20: Absolute value of reconstructed signal.

- Applying thresholding to the reconstructed signal.

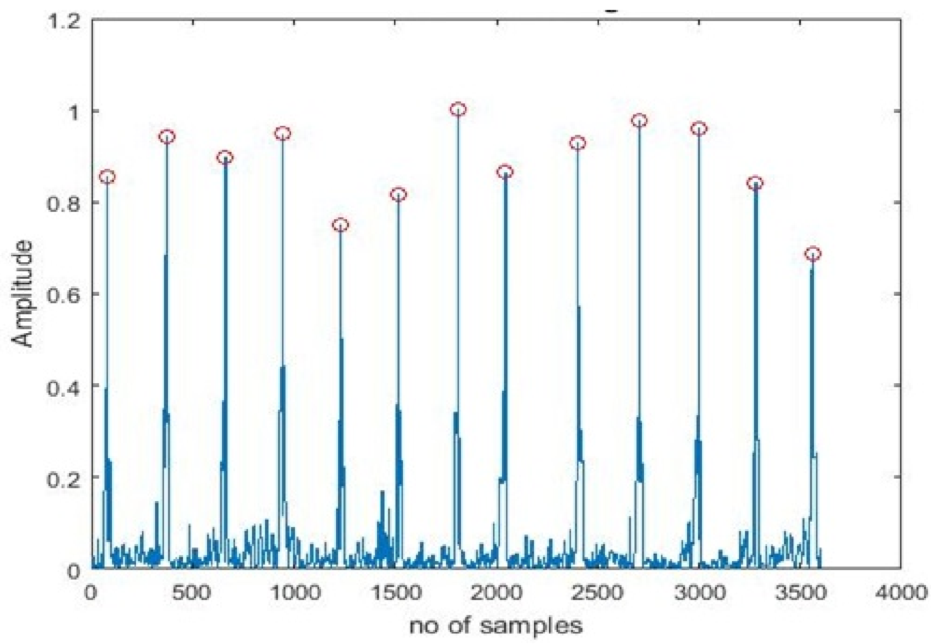

Figure 21: R peak detected after first threshold.

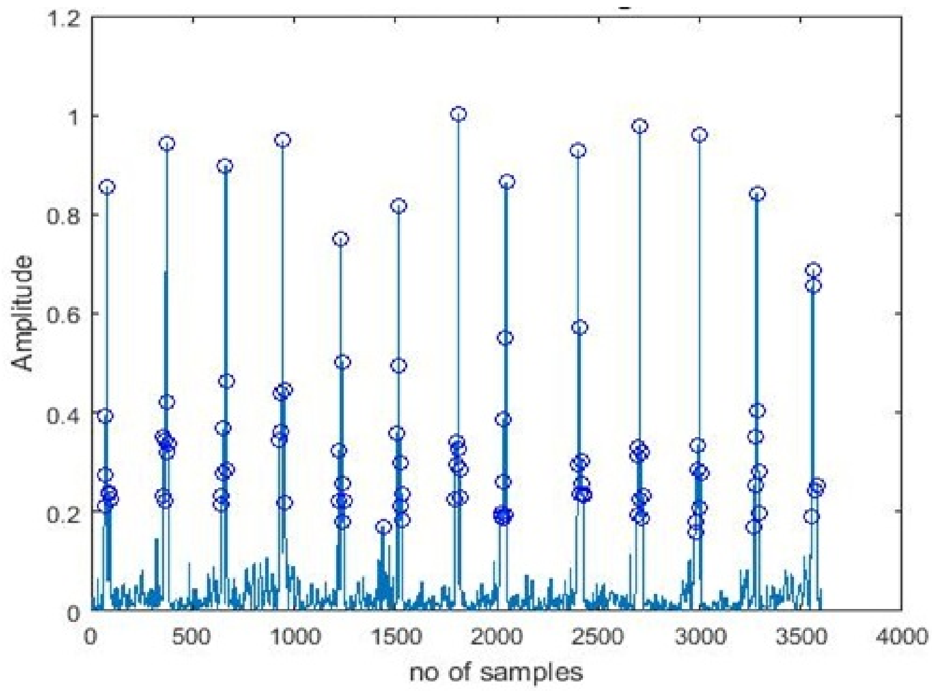

Figure 22: R peaks detected after two thresholds.

Record	TP	FP	FN	Se
100	2272	0	1	99.96
101	1865	2	0	100
102	2187	0	0	100
103	2084	0	0	100
104	2236	4	0	100
105	2572	5	5	99.80
106	2034	5	3	99.85
107	2136	0	1	99.95
108	1762	8	5	99.71
109	2532	3	0	100
111	2124	4	0	100
112	2633	1	0	100
113	1795	0	0	100
114	1879	4	0	100
115	1953	6	0	100
116	2427	1	5	99.79
117	1530	1	0	100
118	2275	5	2	99.91
119	1987	4	2	99.89
121	1868	4	0	100
122	2581	0	0	100
123	1619	5	0	100
124	2610	8	0	100
Total	46591	70	24	99.94

Table 3: Analysis of proposed algorithm for R peak detection.

Here 'Se' is the sensitivity which is defined by $Se(\%) = \frac{TP}{TP+FN} * 100$

TP is True Peaks Diagonised, FN is the actual peaks that are not being detected, FP is the peaks detected that are not really present.

4.6 Summary

From this chapter we obtained various parameters for the efficiency evaluations. From the algorithm of MA filter we got an enhanced signal with a cross-correlation of 0.9273. While for the DWT algorithm it was 0.9031. Hence we found out that the DWT is better in comparison to MA filter as the drawback of latter is loss of data which is very important for ECG components extraction. Along with the enhancement we found out the R peaks of various ECG data and finally computed the sensitivity which came out to be 99.94

Chapter 5
Conclusion and Future Scope

5 Conclusion and Future Scope

5.1 Conclusion

In this research work, the main component of importance in is the Electrocardiogram (ECG) signal. Main motive in this work is to analyze the signal for enhancement process along with detection of the most important ECG component. Finally my focus has been to enhance the ECG signal and have a better correlation with the final reconstructed signal.

• A real time analysis of ECG signal was implemented by using the proposed algorithm for MA filter for removing baseline wander noise. The cross-correlation was found out to be 0.9273 with loss of data required for the ECG components extraction.

• In DWT analysis the BW noise was combined for the enhancement. The computation time was found to be less with the cross-correlation factor found to be 0.9031. Hence we concluded from both the methods that DWT decomposition method for ECG enhancement is better compared to traditional Moving Average filter.

• During R peak detection,we followed two threshold methods . The first threshold method was used to obtain peaks by using an adaptive window while the second threshold method was used by finding the average of R-R peaks and the matching it with the first threshold output.

• After finding the R peak for the typical signal, we found out for different ECG data from database inorder to extract the true peak, false positive and false negative and then compute the sensitivity which was finally found out to be 99.94

5.2 Future Scope

The above thesis work implements proposed algorithm for enhancing and delineating the component of the ECG signal taken. But lots of work can be implemented in this field in future.

- Better model can be proposed with modified algorithm
- EMG removal techniques for better correlation.
- Using ECG for hardware interfacing such as for biometric applications

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